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The Status and Prospects of Virtual Reality in Chemical Engineering

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Introduction

Virtual reality, VR, is a rapidly developing computer interface that strives to immerse the user completely within an experiential simulation, thereby greatly enhancing the overall impact and providing a much more intuitive link between the computer and the human participants. VR has been applied successfully to hundreds if not thousands of scenarios in diverse areas of art, architecture, medicine, military training, theatre, music, dance, archeology, history, rapid prototyping, manufacturing, entertainment, biology, chemistry, sales, business, financial analysis, scientific visualization, engineering, and education. Although the authors are only aware of a single research group working specifically on the application of VR to chemical engineering education, there are an increasing number of projects in closely related fields, and there are many reasons to forecast a positive future for VR in chemical engineering. This paper will first describe the current status of VR development for chemical engineering education, and then discuss some of the future trends in the field.

Background: Description, Features, and Benefits of Virtual Reality

The overriding goal of VR developers is to create a simulation that is so realistic and so involving that the participant(s) can not distinguish it from the real world. while this ideal has not yet been achieved, some high-end systems are quite effective at suspending the disbelief of the participants and blurring the lines between reality and simulation. Less expensive (i.e. student affordable) systems provide many of the benefits and features of VR in a less realistic environment.

Tools used to deliver VR commonly include the following:

1. A computer with high speed graphics capabilities. In order for a simulation to be believable, the graphics images should ideally be re-calculated and redrawn at least 30 times per second. (Note that VR images are not stored graphics like those used in many computer games, but are actually calculated and re-calculated on the fly.) The complex 3 dimensional rendering calculations require significant computing power, in addition to any calculations necessary to run the simulation itself. Stereoscopic imagery approximately doubles the graphics calculational load. The computer and appropriate software are the only required components of VR. All remaining items are optional components that enhance the quality and believability of the simulation.

2. A head-mounted display, HMD. The HMD is a viewing device worn by the user that enhances the experience in several important ways. First of all, it frees the user from watching the traditional monitor, and furthermore blocks his/her vision so that only the simulation is visible. This sensory deprivation concentrates the user's attention so as to help the user forget about the existence of the

real world. Secondly, HMDs are usually equipped with head tracking sensors, which allows the simulation to adjust the graphics images according to where the user is looking. This feedback provides an intuitive feel to the virtual world that greatly enhances its effectiveness.

3. Wired glove(s) or other wired clothing. These devices effectively attach sensors to the user's hand(s) and/or other body parts, which provide position and orientation data to the computer. This data is used by the simulation to adjust the appearance of virtual hands, etc. seen within the virtual world. Users are then provided with an intuitive interface that literally allows them to reach out and touch their simulations. Advanced versions provide a sense of physical touch and/or force feedback.

4. Other esoteric devices either in existence or under development provide additional capabilities, such as 3-dimensional (stereoscopic) vision, 3D localized sound cues, olfactory display, near-weightless suspension, and interfaces to special equipment such as bicycles, wheelchairs, treadmills, and even golf clubs. some of these devices are designed to improve the overall realism and impact of all VR simulation, while others are designed for special applications.

The main benefits offered by VR are the increased impact of the simulation provided by total immersion in the experience, and the intuitive interface that allows participants to interact with the simulation in a more natural manner. To evaluate the former benefit, consider the difference between visiting a chemical plant and inspecting and operating the equipment versus reading about it in a textbook. Even with color photos (and movies), most students will remember the hands-on experience far longer than the traditional presentation. An example of the intuitive interface is the use of VR by pharmaceutical researchers in North Carolina to *feel* the intermolecular forces involved in drug-protein docking mechanisms[9]. The VR interface gives them a much better understanding of the forces involved than they would get from reams of numbers, and this improved understanding is greatly speeding up the drug development process.

Educational applications of VR benefit not only from the power of experience, but also from the ability to reach students having different *learning styles*[12]. Traditional text-and-lecture education, for example, is primarily a *verbal* activity. While many students learn well in such an environment, there are many other students who are more *visual* in nature, and those latter students benefit from more visual stimulus, such as graphs, pictures, movies, and virtual reality. Other facets of learning styles that can benefit from VR include those students who learn best from participatory activities, and those who must see the big picture before the details make sense (global learners.)

The Status of Virtual Reality in Chemical Engineering Education

Work is in progress in the Department of Chemical Engineering at the University of Michigan to develop and evaluate a series of VR based modules for undergraduate education, under a grant recently awarded from the National Science Foundation. The goals in developing these modules are threefold:

1. To produce modules with as much practical use to as many students as possible.
2. To determine what educational situations (courses, topics, and students) will benefit most from virtual reality.
3. To develop a knowledge base of techniques for the display of, and interaction with, scientific and technological information and concepts in a virtual world, that can later be applied to practical engineering problems

The first goal is a rather evident one, to produce a valuable product that will have as strong a positive impact as possible on the undergraduate education of as many students as possible on a nationwide scale. This goal implies a restriction to working with computer technology that is either readily accessible to most students, or else will be by the time our projects are completed. This restriction raises some very interesting constraints in terms of developing a useful simulation that runs effectively on minimal and often conflicting hardware requirements.

The second goal addresses the important issue that virtual reality is a brand new tool in the technical educator's toolbelt. In order to use this tool effectively we must study not only the mechanics of the tool's operation, but we must also ascertain exactly the types of problems to which this new tool can best be applied. Some of the most appropriate problems may have never been considered or even acknowledged, if there has never before been a way to address them.

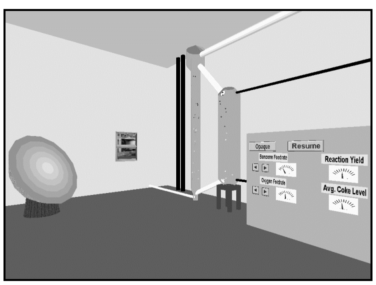
The third goal points out that much of the knowledge and experience gained in developing technical education VR applications can later be applied to practical engineering problems, probably using more advanced equipment and tools than for the educational applications.

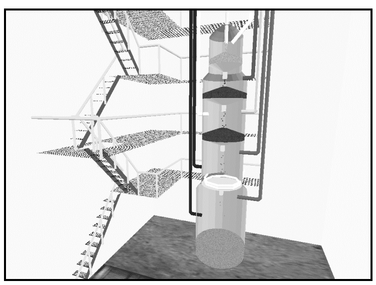
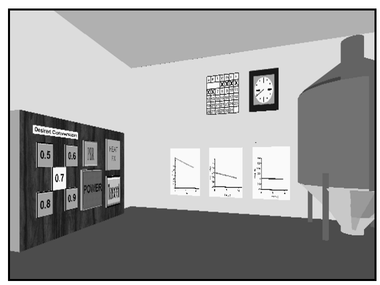
Progress has been made towards all three of these goals, with the most apparent results being a series of three major applications and seven smaller test programs. The former are designed to be useful educational tools for selected topics in chemical engineering, whereas the latter are primarily exploratory forays and examples to determine and illustrate some of the capabilities of VR as applied to technical education. The major applications have undergone testing by over 200 students in multiple classes at the University of Michigan and are currently commencing beta testing at other universities. The minor applications may or may not be expanded upon in future development efforts.

Vicher 1

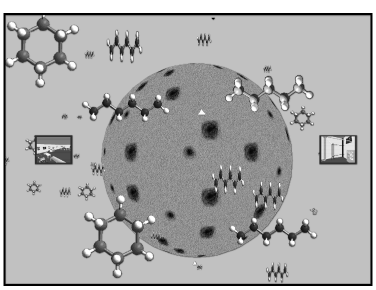
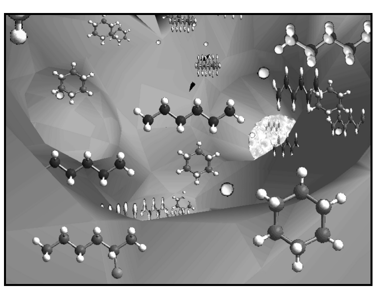
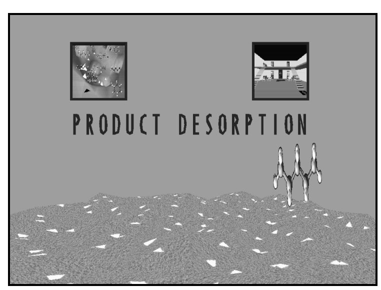
Vicher 1 is a virtual simulation of a modern chemical plant, focusing on catalyst decay and different methods of handling this problem on an industrial scale. Students start out in the welcome center, and then move on to explore more significant areas.

Rapid decay of catalyst is studied in the transport reactor room, where students can operate and explore a vertical straight through transport reactor and associated catalyst regenerator. Medium rates of catalyst decay are handled in a moving bed reactor, and slow decay is studied in the time-temperature room.



On a microscopic scale, students in Vicher 1 can observe diffusion surrounding a single catalyst pellet, and can then fly inside the pores of the catalyst to observe reactions occurring at the molecular level. Zooming in still further shows a single molecule reacting on the surface inside the catalyst pore.

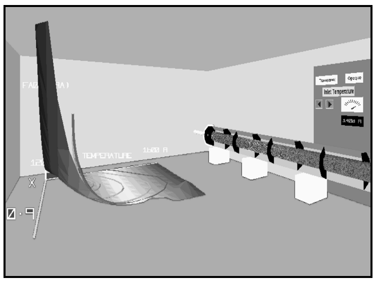




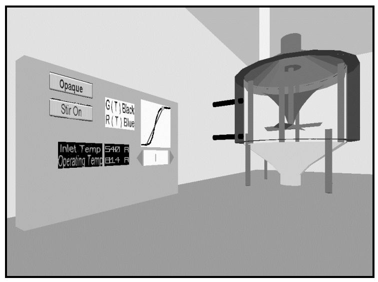
Vicher 2

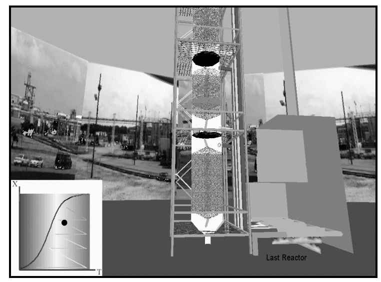
Vicher 2 is another interactive virtual chemical plant simulation, focusing on non-isothermal effects in chemical kinetics and reactor design. Doors from the welcome center lead to three different engineering areas.

In the non-isothermal packed bed reactor room, students observe changing temperatures down the length of a reactor as the inlet temperature is adjusted. A three dimensional display of the kinetics involved helps students to understand the reactor's response to their adjustments.

The multiple steady states room illustrates a continuous stirred-tank reactor that can have different equilibrium operating conditions for identical control settings, depending on how these conditions were reached. The staged reactor area shows multiple reactors in series with interstage heating, used to overcome equilibrium limitations at lower temperatures.







Safety

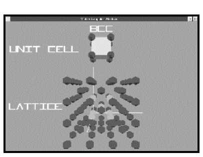
Safety is another virtual chemical plant, that differs from the Vicher simulations in two important respects. On the one hand, it is a non-functional world, in that there are no operational control panels, but on the other hand it contains a much higher level of realistic detail, since it is based upon photographic data taken at an actual chemical production facility. There is an extensive help facility in both the Vicher applications and Safety. In the latter case, the help window includes photographic detail that would not otherwise be possible in a virtual reality simulation.

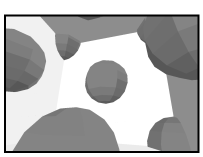
Exploratory Applications

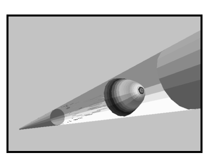
In addition to the three major applications described above, a number of smaller applications have been developed, in order to explore the capabilities of VR as an educational tool, and to test and illustrate particular techniques. These applications can be categorized roughly into two areas: three dimensional spatial relationships, and the exploration of information space.

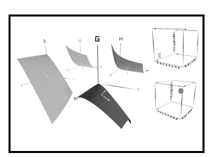
One of the powerful features of virtual reality is the ability it provides to see how things fit together in three dimensional space. VRiChEL applications for applying this to chemical engineering include crystal structures, and fluid flow velocity profiles.

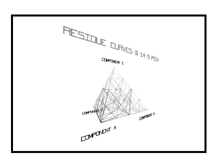
Virtual reality also offers the ability to explore spaces composed of pure information, with no walls or tangible objects as such. VRiChEL applications that explore the informational capabilities of virtual reality include Maxwell's Relationships, Azeotropic distillation residue curves, and the periodic table of elements.











Knowledge Gained in the Development of the VR Modules

One of the major goals of the VRiChEL laboratory is to develop a knowledge base of information regarding the application of virtual reality to technical education. Although the work is still in progress, a few notable findings have already been made:

1. Virtual reality is a graphical environment, not well suited to text-based information. While this seems self-evident, there are several important ramifications:

   a) Traditional computer instruction methods do not apply to VR. It is not practical to provide students with on-screen textual information or expect them to type in responses to questions. (We have had some success in delivering textual information in a separate window, but head-mounted display users can not read it, and many users choose not to.)

   b) The students who are most attracted to VR and who are most affected by it are those who have less of a tendency to read than many of their counterparts. (Visual learners as opposed to verbal learners.) Therefore we need to keep any written instructions as brief as possible, and we cannot count on students reading textual information within the simulation, even when the latter is possible.

   c) Since text cannot be counted on to deliver information in a virtual world, an alternative mechanism must be devised. Audio narration works well, assuming that students can hear the simulation. (Misplaced headphones, technical malfunctions, and physical handicaps can all present difficulties.) In our simulations we have developed virtual television sets that provide both audio and video information delivery.

2. VR does not purport to replace traditional educational methods, nor is it appropriate or beneficial for all subjects or all students. VR is most useful as a supplement to traditional methods, for students who have difficulty grasping the material based upon written and oral presentations. Topics most suited to VR are those that involve the visualization of environments and concepts that are normally beyond the students' reach, such as microscopic, hazardous, or abstract worlds.

3. VR is better suited to the qualitative illustration of concepts than to an exact quantitative presentation of information or data. There are two important reasons for this, both of which can be expected to change within the next 5 to 10 years. The first is that VR requires frame updates of 20 to 30 frames per second for optimal performance, which necessitates using every available CPU cycle to render graphics, and leaves little computing power for rigorous engineering calculations. The second reason is that currently affordable head-mounted display devices have such poor visual resolution that fine details are indistinguishable in any case.

4. The biggest area of student difficulties has been with navigation and orientation. Therefore anything that can be done to improve these two key areas will improve the overall simulation. Two examples from our own work are the use of teleports to move from room to room, and non-symmetrical spaces to provide directional cues.

5. We have also developed a number of technical methods for implementing educational VR, such as moving (and reacting) molecules, interactive help, virtual televisions, and functional control panels. While the details are beyond the scope of this paper, they will appear on our web page (http: //www.engin.umich.edu/labs/vrichel) and a future paper covering our findings in educational VR.

Continuing Work

Work in progress includes the further refinement of the existing modules, development of additional modules, and the porting of new and existing modules to alternate platforms so as to reach a wider potential audience. Initial beta testing is commencing at locations beyond the University of Michigan campus. (Over 200 students in several courses at UM have already tested the modules.) If possible, we would like to release some of the modules for widespread use on the next volume of the CACHE corporation's educational CD-ROM.

The Prospects for Future Development of Virtual Reality

The future prospects for virtual reality in chemical engineering and in education are very good. We can expect to see the use of this medium expand tremendously over the next five to ten years. Here are a few of the developments that support that conclusion and indicate the future direction of VR:

1. The capabilities of modern computing equipment continue to increase at an astounding rate. Performance that was once relegated to multi million dollar super computers now sits on a desktop and competes in the personal computer marketplace. At the same time the abilities of personal computers are constantly increasing to match the performance of their big brothers. This exponential trend in performance/price ratio has continued for over twenty years, and there is every reason to expect that it will continue to do so.

Already there are high-end personal computers available for under $20,000 (under $15,000 educational pricing) that compete favorably against and sometimes outperform Silicon Graphics workstations in virtual reality applications. At the same time, the prices on Silicon Graphics computers have dropped, with desktop offerings between $20,000 and $50,000 (undiscounted) for VR capable machines. ($35,000 to $50,000 for hardware level texture mapping, which is usually required for top quality VR.) As these prices continue to drop, we will see more and more of these high-powered graphics computers appearing on college campuses, first in the research labs and later in the open student computing areas.

2. In addition to computers themselves, there are also tremendous advances being made in graphics cards and standards for existing computers, fueled primarily by the computer gaming industry and also by PC based CAD and graphics programs.. Microsoft Windows NT now supports the OpenGL graphics standard, which is based upon the graphics language originally developed by Silicon Graphics for their graphics supercomputers. As a result, several manufacturers have begun producing OpenGL graphics accelerator cards to enhance PC graphics under the Windows NT operating system, and software vendors are also supporting the OpenGL standard. At the same time, Microsoft Windows 95 supports Direct3D, another emerging graphics standard, and as a result there are several Direct3D graphics accelerator cards available and software products which support this new standard. Already VR on a laptop computer is becoming possible as a result of these new advances. One industry expert predicts that within 6 months there will be $200-500 3D accelerator boards for the PC that deliver the same performance that a $5,000 board did just one year ago, and that within a year almost all VGA boards and many motherboards will incorporate built-in 3D rendering. Many of the constraints placed upon VR developers using student-affordable equipment will no longer be an issue in the next few years.

3. Hardware improvements are not limited to only computing and graphics devices, but also extend to the peripherals necessary to fully appreciate virtual reality simulations. When VR first started, all the peripheral devices had to be individually crafted, at a cost of millions of dollars in the case of some high-end military display units. Later some enterprising individuals learned how to make head-mounted displays using the 0.7 inch television screens that were mass produced for camcorder viewfinders. The problem with this solution is that the viewfinder screens have relatively poor

resolution, and the signal further degrades in the conversion process from a computer VGA signal to a television NTSC signal. Now as virtual reality continues to grow in popularity, manufacturers are beginning to produces head-mounted displays that take VGA signals directly and deliver VGA resolution to the user. Although the prices are still in the (tens of) thousands of dollars, they continue to drop as increasing popularity permits mass production and economies of scale. Similar advances are also being made in terms of wired gloves, 6 DOF mice, and other peripheral devices.

4. In addition to the hardware, the software required to develop a virtual world is rapidly becoming more powerful and user friendly. No longer is it necessary to know C or any other programming language to build simple yet impressive virtual worlds. There are now graphical interface programs that allow the user to point, click, and drag menus to construct and interact with virtual worlds. Simple actions (e.g. gravity or a moving vehicle) can be added using an easy to learn scripting language. Software packages are becoming more powerful, with added features such as transparency, reflectivity, colored lighting, and automatic detail refinement. (The latter technique involves rendering an object with a low amount of detail when the user is far away, and then switching to a highly detailed version as the user approaches.)

5. The number of applications being developed using VR is also growing exponentially in almost every field of science, art, entertainment, and industry, including both engineering and education. VR is fast becoming a popular tool for both engineers and educators, and therefore engineering educators cannot be far behind. Here are just a few examples of activity involving VR, education, and engineering:

   a) The Virtual Reality in Education Laboratory at East Carolina University has put together an on-line bibliographic listing of over 300 references to journal articles on the topic of VR in education. (ftp://ftp.hitl.washington.edu/pub/scivw/ citations/VR-ED.html) Although most of these citations relate to K-12 education, there is increasing interest in applying VR to higher education.

   b) The Human Interface Technology Lab's knowledge base project contains links to over 150 different research groups and projects involving VR, spanning 19 different countries and 50 American universities. (http:// www.hitl.washington. edu/knowledge_base/onthenet.html) Other categories on the same web page list 30 different educational links and 20 relating to training.

   c) Construction engineering firms, longtime users of high-end CAD systems, have begun modeling their projects (including chemical plants and refineries) in VR to check for design flaws, hazards, and operability prior to construction.

   d) The Boeing 777 airplane was completely designed, developed, debugged, and tested in VR, with no physical prototypes being made. The first 777 manufactured was sold to a customer.

   e) Motorola has used VR to train factory workers, and found the method to be more effective than using actual factory equipment for training.

   f) NASA has developed a virtual windtunnel that allows scientists and engineers to move about the airfoil under study without affecting air flow patterns.

6. Virtual reality is riding the wave of the expanding world wide web. The Internet has existed for a long time as a world wide computer network. Until the last 5 years, however, its use was limited to those with sufficient technical knowledge and equipment to connect to remote sites and access the information stored there. Around 1990 a program called “gopher” was developed at the University of Minnesota, which made it much easier to navigate the ‘net and download files, but the interface was still text-based and keyboard driven. Shortly thereafter the HyperText Markup Language (html) was developed at CERN in Switzerland, and with the advent of the graphical web browsers Mosaic and Netscape, the web as we now know it was born. The simplicity and ease of use of html,

coupled with widespread consumer connectivity, has blown the web into a conflagration that is expanding at a phenomenal rate. (The introduction of commercial uses of the web, including advertising and corporate web pages, has only served to fan the flames.)

As the web has grown in popularity and utility, many new web players, or “plug-ins” have been developed, for playing sounds, movies, and many other media. The latest development in this area is VRML (pronounced vermil), the Virtual Reality Markup Language. The VRML 1.0 standard allowed developers to place three dimensional objects and spaces (e.g. buildings) on their web pages, and allowed those with VRML browsers to view those objects and spaces from any desired viewing angle. Much of the graphics was simple and slow, but it did allow interactive 3-D graphical objects to be viewed over the world wide web. VRML standard 2.0 added a lot of new features, but there were some initial difficulties in getting all parties to agree upon the "standard". Now that this standard is becoming widely agreed upon by the web community, it will soon be possible to distribute true virtual worlds over the world wide web interface. In a related vein, at least one VR software development company[17] has made a Netscape plug-in freely available on their web site (http://www.sense8.com) for viewing virtual worlds developed with their software.

As the world wide web continues to grow exponentially in popularity and power, and as the VRML capabilities continue to grow with it, there can only result an expanding and widespread proliferation of virtual reality applications worldwide.

7. More locally to the University of Michigan, work is now completing on the Media Union, a multi million dollar complex devoted to information transfer and communication through a wide variety of media, including print media (i.e. the library), electronic media, (hundreds of networked work stations spread throughout the building), music, performing arts (dance, etc.), artistic expression (wood, clay, metal, paint, sculpture, etc.), multimedia, computer visualization / graphics, and virtual reality. Included within this center will be a state-of-the-art virtual reality lab housing the latest available technology and software, from personal computer based solutions through a supercomputer powered CAVE. A new course offering for the Fall semester will teach virtual reality concepts and implementation strategies to fifty students from all campus disciplines, with no pre-requisites other than senior standing.

Conclusions

Virtual reality is a powerful computer interface that is increasing in popularity, power, and performance/price ratio on a daily basis, and can be expected to continue doing so for some time to come. The only known applications of VR to chemical engineering education at this time are those developed at the University of Michigan, but this can be expected to change based on the increasing use of VR in both the educational and engineering fields, and with the increasing ease of VR development.

Educational virtual reality applications being developed in the chemical engineering department at the University of Michigan currently consist of three major simulations and 7 minor test applications. The three major applications (Vicher 1 and 2 and Safety) collectively include 7 engineering production areas, three microscopic areas, two welcome centers, and one aerial exploration of a chemical plant and surrounding neighborhoods. Over 200 students have tested the programs at the University of Michigan, and off-site testing is now commencing. It is hoped that widespread distribution can begin with the next volume of the CACHE corporation CD-ROM.

The topic of this paper is far too extensive to cover completely in a document of this size. For further information see the papers and books listed in the bibliography, or visit the web site of the Virtual Reality in Chemical Engineering Laboratory, at http://www.engin.umich.edu/labs/vrichel. The latter resource contains not only the most complete and up-to-date descriptions of the work being conducted at Michigan, but also links to hundreds of other web resources concerning virtual reality and engineering from around the world, including all links referenced in this paper. Color images of our work are available on the web page, as are VRML and WorldUp versions of some of our simpler applications.

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Author Biographies

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